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The Plant Hormones — Their Occurrence in Foods And Possible Role in Human Physiology

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Born in Pennsylvania and educated in the secondary school system of New York City, Dr. Vlitos next studied at Oklahoma State University where in 1948 he obtained his B.S. degree with a major in Botany and Plant Pathology. The following year he was Atkins Fellow in Tropical Agriculture at Harvard University. His graduate work was continued in the mid-west where he obtained an M.S. degree in Plant Pathology at Iowa State College in 1950. Back again to New York City, in 1953 he was awarded his Ph.D. degree in Plant Physiology from Columbia University.

During his return to the east, Dr. Vlitos was senior fellow in plant Physiology of the Union Carbide Chemicals Agricultural Research team at the Boyce Thompson Institute for Plant Research, Inc. from 1950 to 1959. Major research projects included basic studies of the naturally occurring hormones of tobacco and other crops, including evaluation of new plant growth regulators. Then in 1959 he was appointed to his present position as Director of Research for the Central Agricultural Research Station in Trinidad. This station is operating programs of research in plant physiology, pathology, entomology and agronomy. The objective is to broaden the scope of sugar cane research in the West Indies.

Dr. Vlitos is a member of the American Society of Plant Physiologists, Sigma Xi, Phi Kappa Phi, and is a guest scientist of the Brookhaven National Laboratory. He served as organizing secretary of the Fourth International Conference on Plant Growth Substances held in August, 1959.

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The Plant Hormones — Their Occurrence in Foods And Possible Role in Human Physiology

A. J. Vlitos, Ph.D.

INTRODUCTION

A discussion of plant growth hormones or auxins in a journal concerned with nutrition may, at first glance, seem somewhat out-of-place. Plant hormones and human nutrition are two subjects which rarely, if ever, have been reviewed jointly. However, in view of the substantial progress made in recent years in understanding the chemical structure of the phytohormones it seems appropriate to record such new information in a journal concerned with foods and their metabolism.

Many food plants contain substances which, in extremely minute quantities, exert profound physiological effects in the cells of plants, and conceivably in other living tissues as well. It is, therefore, essential that nutritionists and animal physiologists be aware of the nature of the phytohormones and, in particular, that they know something about the chemical structure of phytohormones.

The present review stresses the chemistry of the naturally-occurring plant hormones, the food plants in which they occur, and the possible role that these substances may play in human physiology.

It is an opportune moment in the history of the plant hormone concept to outline the tortuous course of its development. The field is now in a "state of flux". Results of recent research, carried out within the past five years, have prompted a re-evaluation of older theories and of text book definitions. Therefore, a brief section dealing with the historical events leading to the modern concept of phytohormones is included to orient readers to whom the field may be new.

HISTORICAL

Most of us have at some time or other noted that plants are sensitive to external stimuli, particularly to light and to gravity. We have watched a houseplant bend towards an incoming path of light and gradually arrange its leaves with the blades perpendicular to the light stimulus. In 1879 Charles Darwin became interested in the response of plants to light (phototropism). The results of his subsequent studies on the subject were published in a volume called *The Power of Movement in Plants*.[18] The modern history of plant hormones in a sense began with that publication.

Darwin observed that when a coleoptile* of canary-grass (*Phalaris canariensis*) seedlings was illuminated from one side it curved towards the source of light. The curvature or bending took place at a considerable distance below the

*The coleoptile is a tube-like first leaf produced by grasses upon germination. Coleoptiles do not grow as well in the light as they do in darkness.

tip of the coleoptile. If the extreme tip was removed or if it was covered with a light-proof material, such as tinfoil, bending did not occur, although the rest of the coleoptile had been exposed to light. These simple experiments with a few grass seedlings, a razor blade, some tin-foil, and light served as the rudimentary basis for the beginnings of a hormone concept in plants. Darwin postulated that light was "perceived" by the tip and that some "influence" must have been transmitted from the stimulated tip to the more basal areas of the coleoptile, where bending occurred.

It is not until 1911 that Boysen-Jensen[9] expanded upon Darwin's observations and proved that the "influence" or "stimulus" from the tips of oat (*Avena* sp.) coleoptiles could pass through non-living materials, such as gelatin. Paál[55] in 1919 confirmed the studies of Boysen-Jensen; in addition, he found that replacement of the severed tip on one side of the coleoptile stump would produce curvatures away from the treated side. A replacement of the effect of lateral light by an asymmetrical distribution of some stimulus produced by the tip indicated to Paál that the "tip of plants is the seat of a growth-regulating center". He came to the logical conclusion that: (1) a substance or a mixture of substances is formed in the tip and secreted internally and (2) this substance is equally distributed on all sides of the plant, moving downwards through the living tissue. He reported: "If the movement of this substance is disturbed on one side a growth decrease on that side results, giving rise to curvature of the organ." Paál's concept is still widely accepted today, with some modifications.

Probably the most important single impetus to the plant hormone field came as a result of the work of Went,[89] who managed to collect in agar blocks the substances produced by coleoptile tips. He developed the now famous and classical Went *Avena* coleoptile curvature assay for the quantitative determination of auxin, a term used by botanists to describe unidentified plant hormones. Went's bioassay was sensitive to within 10^{-2} micrograms of indole-3-acetic acid, the synthetic substance used as a standard in auxin bioassays. The degree of curvature of decapitated coleoptiles was measured after agar blocks, containing the substances extracted from various plant tissues, had been placed asymmetrically on decapitated coleoptiles. The details of the procedure are discussed in several references.[1,41] Went's bioassay was a most important contribution for three reasons: (1) it stimulated research, (2) it permitted the convenient concentration of active substances and (3) the sensitivity of the test allowed workers to detect as little as 10^{-2} micrograms of auxin when based on the standard, indole-3-acetic acid.

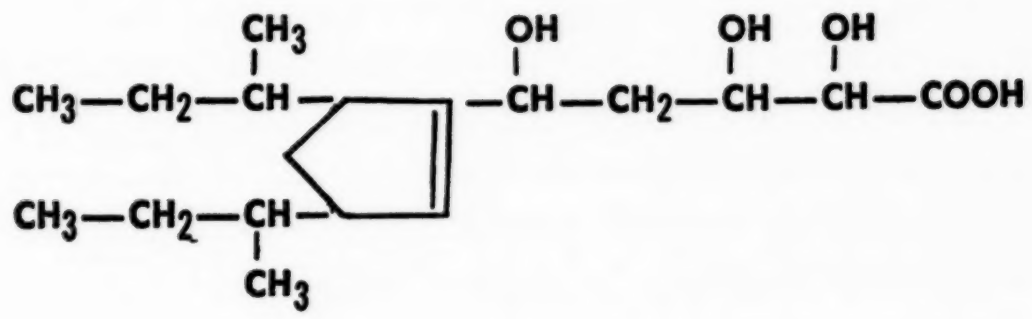
Twenty-nine years after Darwin's simple experiments plant physiologists realized that phototropism, responses to gravity, and growth of plants were in some mysterious way regulated by minute quantities of chemicals, termed auxins or phytohormones. At the present time, however, not all of these substances have been characterized chemically nor are their modes of action fully understood.

CHEMISTRY OF THE PLANT HORMONES

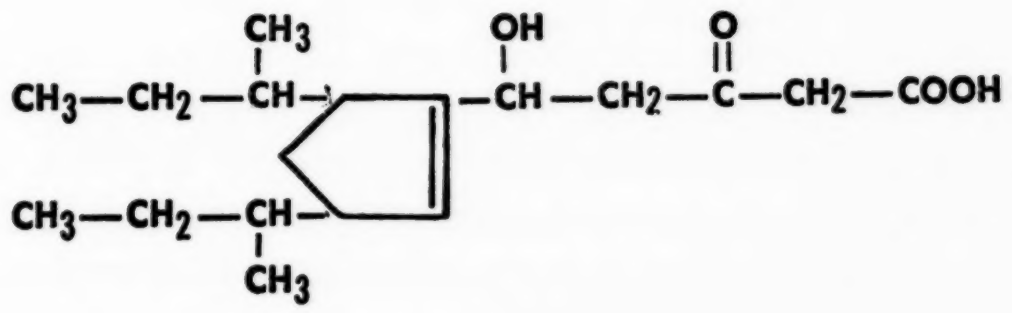
Initial Isolations From Urine. Although the determination of chemical struc-

ture of the phytohormones has lagged behind similar efforts in human endocrinology, it should be realized that the history of the plant hormones has been studded with most unusual circumstances. First of all, the initial isolation of a crystalline substance with plant hormone activity was achieved not from plants but from human urine.[36] It was found that the most prolific source of auxin came from the urine of an eighteen year old youth. Mixed urines originating from patients in a Utrecht, Holland hospital were found to contain one fifth less the activity of the youth's urine.[36, 37] Eventually Kögl *et al.*[37] turned to plant sources and managed to isolate two auxins from corn germ oil. The two substances were named auxin *a* and auxin *b*. (Auxin comes from the Greek meaning to induce growth). Kögl and Erxleben[35] studied the chemical properties of auxine *a* and *b* and suggested the following structural formulas:

Auxin a



Auxin b



These formulas have never been verified by syntheses nor have other workers been able to repeat their isolations. Using highly sensitive bioassays, Wieland *et al.*[91] were unable to detect these substances though Kögl's original procedures were followed as closely as possible. Few, if any, plant physiologists today accept auxin *a* or *b* as authentic naturally-occurring phytohormones.[1] They have been discussed here primarily because of their historical interest. One cannot lightly dismiss the brilliant chemical researches of Kögl, Haagen-Smit, and their associates. It may well have been a twist of fate that the urine used for the original isolations of auxin *a* and auxin *b* came from patients who had been on unusual diets or who had been suffering from a metabolic disorder resulting in excretory products containing these two compounds. This is, of course, purely speculative.

Indole-3-acetic Acid. After Kögl and his co-workers found that the plant growth hormone content of urine from various individuals varied as much as five-fold, they attempted to improve their isolation procedures. In so doing they obtained an entirely different active product which they termed "heteroauxin" (the other auxin) to differentiate it from auxins *a* and *b*.[37] Analysis of heteroauxin proved it to be indole-3-acetic acid (IAA). Kögl *et al.* did not consider

IAA to be a "true auxin" but rather an "excretory by-product." History has confirmed that IAA is probably the major phytohormone occurring naturally in plant tissues. Actually, the chemical was synthesized as early as 1904 in Germany by Ellinger.[20] Thimann[80] in 1935 demonstrated that IAA was identical to "rhizopin," a plant growth substance that had been isolated previously from a fungus, *Rhizopus suinus,* by Nielsen.[50]

From 1935 to the early 1950's it was generally accepted as fact that IAA was *the* naturally-occurring plant growth hormone,[8, 24] though it had never been isolated in crystalline form from the tissues of a green plant. In recent years with the introduction of more reliable analytical procedures the concept of a single plant growth hormone has been challenged.[5, 16]

INDOLIC PLANT GROWTH HORMONES OCCURRING IN FOODS

With the advent of paper chromatography there has been a surge of renewed efforts to isolate and to characterize the naturally-occurring phytohormones.*

Several early investigators expressed the then unpopular view that a single hormone could not possibly "catalyze" all of the diverse and complicated processes involved in plant growth. Zimmerman, Hitchcock and their co-workers [27, 96-100] at the Boyce Thompson Institute had shown quite clearly that a variety of synthetic chemicals such as indole-3-butyric acid, 2, 4-dichlorophenoxyacetic acid, naphthaleneacetic acid, substituted benzoic acids, ethylene, and other unrelated and diverse compounds could act as auxins and would produce a variety of physiological responses when applied to plants or parts of plants. Thus, they were able to show that many of the responses of plants attributable to naturally-occurring IAA such as induction of rooting, curvature of stems, production of hyperplasias and tumours and suppression of flowering could be induced with synthetic materials chemically unrelated to IAA. Based on their prolific data, Zimmerman and his associates maintained that the "single hormone concept was over simplified and at best represented an idealized scheme."

Only quite recently has it become abundantly evident that plants contain a variety of substances capable of functioning as phytohormones or auxins. At different stages of growth and development varying hormonal patterns have been detected chromatographically.[43] Different tissues or organs on the same plant may contain different auxins.[43] Considerable evidence also exists that IAA is, in fact, a major phytohormone in the tissues of a number of plants[3, 34, 38, 51, 52, 74] but not in all.[39, 43, 46, 48]

Indole-3-acetic Acid. Several reports of the occurrence of indole-3-acetic acid in plants are based on single Rf values, often in a single solvent system. These identifications, of course, should be verified by further study and, as stressed by Bentley,[5] for the present they should be accepted with caution. However, in many cases the identification of IAA has been supported by biological assays coupled with colorimetric analyses on paper chromatograms. It is now generally accepted that IAA occurs in apple seeds and the plants listed in Table I. The chemical has

*For references see items listed under *Bibliography* marked with an asterisk (*).

TABLE I

FOOD PLANTS KNOWN TO CONTAIN INDOLE-3-ACETIC ACID, INDOLE-3-ACETONITRILE, OR INDOLE-3-PYRUVIC ACID

PLANT	COMPOUND (Isolated or Detected)	REFERENCE
Bamboo Shoots	Indole-3-acetic acid	Koshimizu & Mitsui [38]
Beans	Indole-3-acetic acid	Bennet-Clark & Kefford [3]
Blackcurrant	Indole-3-acetic acid	Wright [93, 94]
Brussels Sprouts and Cabbage	Indole-3-acetaldehyde Indole-3-acetic acid Indole-3-acetonitrile	Larsen [39] Linser, Mayr, and Maschek [43] Kefford [34]
Cauliflower	Indole-3-acetic acid Indole-3-acetonitrile	Kefford [34] Fisher [21]
Citrus (Flowers)	Indole-3-acetic acid	Stowe, Thimann, and Kefford [74]
Coconut Milk	Indole-3-acetic acid	Nitsch & Nitsch [52]
Corn	Indole-3-acetic acid Indole-3-pyruvic acid	Hinsvark, O. N. *et. al.* [26] Stowe & Thimann [72]
Grapes	Indole-3-acetic acid Indole-3-acetonitrile	Nitsch & Nitsch [52]
Gooseberry	Indole-3-acetic acid	Wright [93, 94]
Oat (Coleoptiles)	Indole-3-acetic acid	Söding and Raadts [66]
Peas	Indole-3-acetic acid	Bennet-Clark & Kefford [3]
Soybean (leaves and stems)	Indole-3-pyruvic acid	Vlitos and Meudt [86, 87]
Strawberry	Indole-3-acetic acid	Nitsch [51]

not been detected in tomato,[85] potato,[7] cucumber,[5] soybean,[87] spinach,[85] barley,[85] or apple leaves and apple fruits.[46]

Other Indole Plant Hormones. Indole-3-acetonitrile was first isolated from plant tissues by Jones *et al.*[32] Since then the nitrile derivative has been detected in a number of *Brassica* species,[21] including brussels sprouts and cabbage,[43] as well as in potato peelings,[7] grape seeds and tomatoes.[51] Identifications of indole-3-acetonitrile have usually been based on colorimetric tests on paper chromatograms coupled with biological data in the oat coleoptile or oat first-internode test. The release of indole-3-acetonitrile from a water-soluble, ether-insoluble precursor has been reported by Housley and Bentley.[28] Thimann[81] has suggested that the auxin activity of the nitrile may be due to its rapid conversion, *via* hydrolysis, to IAA, and that the IAA thus produced acts as the growth-hormone.

Indole-3-carboxylic acid and indole-3-aldehyde have been shown to be degradation products of the nitrile.[14]

Indole-3-pyruvic acid has been detected in corn endosperms by Stowe and Thimann.[72] Vlitos and Meudt[87] detected a compound on paper chromatograms which they presumed to be indole-3-pyruvic acid, extracted from tissues of soybean and tobacco. It is unlikely, however, that indole-3-pyruvic acid would remain stable in solvents containing ammonia so more work is necessary to confirm the identification. Bentley *et al.*[6] have synthesized indole-3-pyruvic acid and confirmed its instability under conditions of ammoniacal paper chromatography. The compound is, however, stable in weak acids and has been chromatographed in acetic-acid:water mixtures (1:3 v/v). Indole-3-pyruvic acid is active in the *Avena* straight-growth assay but its activity is much lower than that of IAA.

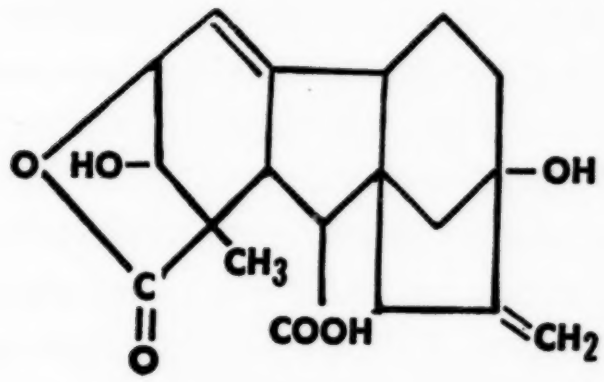
Other indole compounds occurring naturally in foods include indole-3-carboxylic acid,[14, 15] indole and N-methyltryptophan,[74] 5-hydroxy-N,N-dimethyltryptamine,[76] 5-hydroxytryptamine,[59] 5-hydroxyindole acetic acid,[83] and skatole.[5] Most of these substances possess either a low order of plant growth hormone activity or are inactive, depending upon the bioassay which is employed to measure the activity.

At this point it is of interest to note that though the 5-hydroxy indole derivatives have been shown to occur in plants their physiological significance remains doubtful. In animals, bufotenine and serotonin are products of tryptophan metabolism perhaps with 5-hydroxyindoleacetic acid as the end product of metabolism. Bentley has suggested that a similar pathway may exist in plants.[5] Further studies are necessary to clarify this point.

NON-INDOLIC PLANT GROWTH HORMONES

Gibberellins. Recent studies also have demonstrated that plants contain non-indolic plant growth regulators.[16, 48, 58, 84] The most important of these, and by far the most dramatic, are substances which are called the gibberellins. Gibberellins were originally isolated by Japanese scientists from the fungus *Gibberella fujikuroi,* which attacks rice seedlings and produces the disease known as "bakanae" ("crazy-plant"). Bakanae disease is characterized by an unusually rapid elongation of the infected seedling leading to a reduction in yield, if not to complete destruction of the seedling. Through a series of fascinating researches Japanese workers were able to isolate the chemical component responsible for the stimulation of growth in infected rice seedlings. Following World War II, when the Japanese literature was available, British and American teams confirmed the earlier studies. An excellent historical review of the subject is now available.[75] More recently the gibberellins have been isolated from higher plants and have been shown to occur in seeds and fruits of nine genera representing seven families of plants.[58] Although the chemical structure of each of the gibberellins occurring in higher plants and in the fungi has not been established, some similarities in structure have been noted. Cross *et al.*[17] proposed the following structure for the gibberellic acid isolated from the imperfect stage of *Gibberella fujikuroi.*

Proposed structure for *gibberellic acid*



A striking physiological effect of the gibberellins, in contrast to the indole auxins, is the stimulation of growth of intact plants, particularly the induction of rapid elongation of stems.[10]

When gibberellic acid is applied in very small doses (microgram quantities) to both dwarf and tall varieties of peas, the dwarfs are stimulated to grow so that eventually they elongate to the same length as the tall varieties. It has been suggested that the gibberellins substitute for a growth factor lacking in the dwarfs or that they counteract a natural growth inhibitor.[10] More recent evidence has demonstrated that when gibberellic acid is introduced into pea plants there is a resulting large increase in the levels of extractable growth hormones in the treated tissues.[57] This suggests that gibberellic acid may not be acting as a growth hormone *per se* but that it sets into motion a sequence of metabolic events that lead to the production of an active auxin.[57] Pilet[60] found that gibberellins inhibit the enzymes which oxidize indole auxins of carrot tissues. He suggests that the production of excessive quantities of indole hormone may account for the growth activity of gibberellins.

Though the mode of action of the gibberellins is not fully understood there is abundant evidence that these substances are plant hormones operating in a fashion different from that of the indole hormones. Undoubtedly when all the facts are known it may well be that we shall find some interesting metabolic interactions between the indole phytohormones and the gibberellins.

Kinins. A third class of naturally-occurring plant growth factors, which may conceivably be operating as hormones, are the so-called kinins. Jablonski *et al.*[29] reported in 1954 that various natural products such as extracts of malt and vascular tissues contained chemical factors which induced the division of excised pith cells of tobacco in culture. In 1955, Miller *et al.*[49] isolated 6-fufurylaminopurine from an autoclaved sample of *desoxyriboneucleic* acid. They were able to show that this compound, which they named kinetin, would induce cell division in tobacco pith cultures. Skoog and Miller[65] found that many other adenine derivatives also are effective as cell division factors or "kinins". Kinins appear to be ineffective unless IAA is present in the system, illustrating a most interesting example of phytohormone interaction. Of particular interest also is a recent report from Australia that a kinin occurs in apple fruitlets.[22] Steward *et al.*[67-70] have stressed for many years that coconut milk and other endosperm tissues contain growth factors active in stimulating cell division and that these substances definitely were not related to the known indole-containing hormones.

Long-chain Fatty Alcohols. Still another class of naturally-occurring plant growth factors are the long-chain fatty alcohols recently isolated in crystalline form from Maryland Mammoth tobacco.[16, 84] These substances, at extremely low concentrations, promote the growth of excised oat sections. The similarity of the chromatographic characteristics of these particular non-indolic compounds to those of IAA and indole-3-acetonitrile is quite striking. One of the isolates, tentatively identified as 1-docosanol, has an Rf value coincident with that of indole-3-acetonitrile; a second isolate runs at an Rf identical with that of IAA, in solvents generally employed in auxin chromatography. It has been suggested[16] that IAA and indole-3-acetonitrile might easily be confused with these non-indolic growth substances, especially if the identifications are based solely on single Rf values and bioassays without supporting chemical evidence.

A number of synthetic long-chain fatty compounds and related structures have also been found effective in promoting plant growth.[16, 84] Among these are 1-octadecanol, 1-eicosanol, 2-tridecanol, 2-heptadecanol, 2-heptadecanone, 12-hydroxyoctadecanoate, mono- and di-octadecyl acid phosphate, mono- and didocosyl acid phosphate, octadecyl acid sulfate, and phytol. Crosby and Vlitos[16] have indicated that the structural requirements for activity in the fatty alcohols are quite specific; only C_{17} to C_{22} straight-chain alcohols are active. Stowe[71] reported that a number of fatty acid esters promote growth in pea epicotyl sections. Apparently the fatty acid esters act only in the presence of added IAA, suggesting that the esters *per se* are not auxins. Whether or not the long-chain fatty alcohols are "true" phytohormones is a moot question. There is evidence that these substances regulate growth either by acting as co-factors for some other naturally-occurring phytohormone such as IAA[71] or by exerting some unknown physical effect at cellular interfaces.[16]

Long-chain unsaturated fatty acids such as linolenic acid, arachidonic acid, and docosahexanoic acid are assuming considerable significance in animal nutrition. Recently Butenandt *et al.*[12] showed that the sexual attractant of the silkworm (*Bombyx mori*) is an unsaturated primary alcohol, 10, 12-hexadecadiene-1-ol. Also, the active constituent of "royal jelly" has been identified as 10-hydroxydecenoic acid.[13] These recent studies indicate quite clearly that waxes, long-chain fatty alcohols, long-chain fatty acids, and related compounds can no longer be considered inert by-products of metabolism. Although little is known about their respective modes of action it is well-known they tend to aggregate in layers at water-air interfaces. Thus, one is tempted to speculate that their influence on growth is related to their physico-chemical characteristics rather than to their elemental composition. Interactions between the fatty alcohols and other types of plant growth hormones such as the indoles, gibberellins, and kinins, once understood, might well give rise to a novel, multi-phytohormone concept in which each component of the system is dependent on a dynamic equilibrium. A situation of this type would conform more closely with analogous endocrine systems in animals and with other schemes of metabolism containing multiple factors.

New plant hormones shall undoubtedly be isolated in the future. Many may prove to be unrelated structurally to those known today. The field has progressed rapidly from the concept of a single plant hormone to one which is based on more modern concepts of cellular metabolism.

HUMAN PHYSIOLOGY AND PLANT HORMONES

The possible role of the phytohormones in human physiology is a highly speculative one. Since several groups of substances with plant-growth regulating activity occur in foods it is very likely that, upon ingestion, these compounds undergo a sequence of metabolic changes. Whether or not the metabolic intermediates are important in human physiology remains for further research to determine. The present discussion therefore is limited to an outline of some reaction sequences which have been worked out for the indol auxins in plants and in the human. Very little is known about the metabolism of the gibberellins, kinins, and long-chain fatty alcohols either in the plant or in the animal.

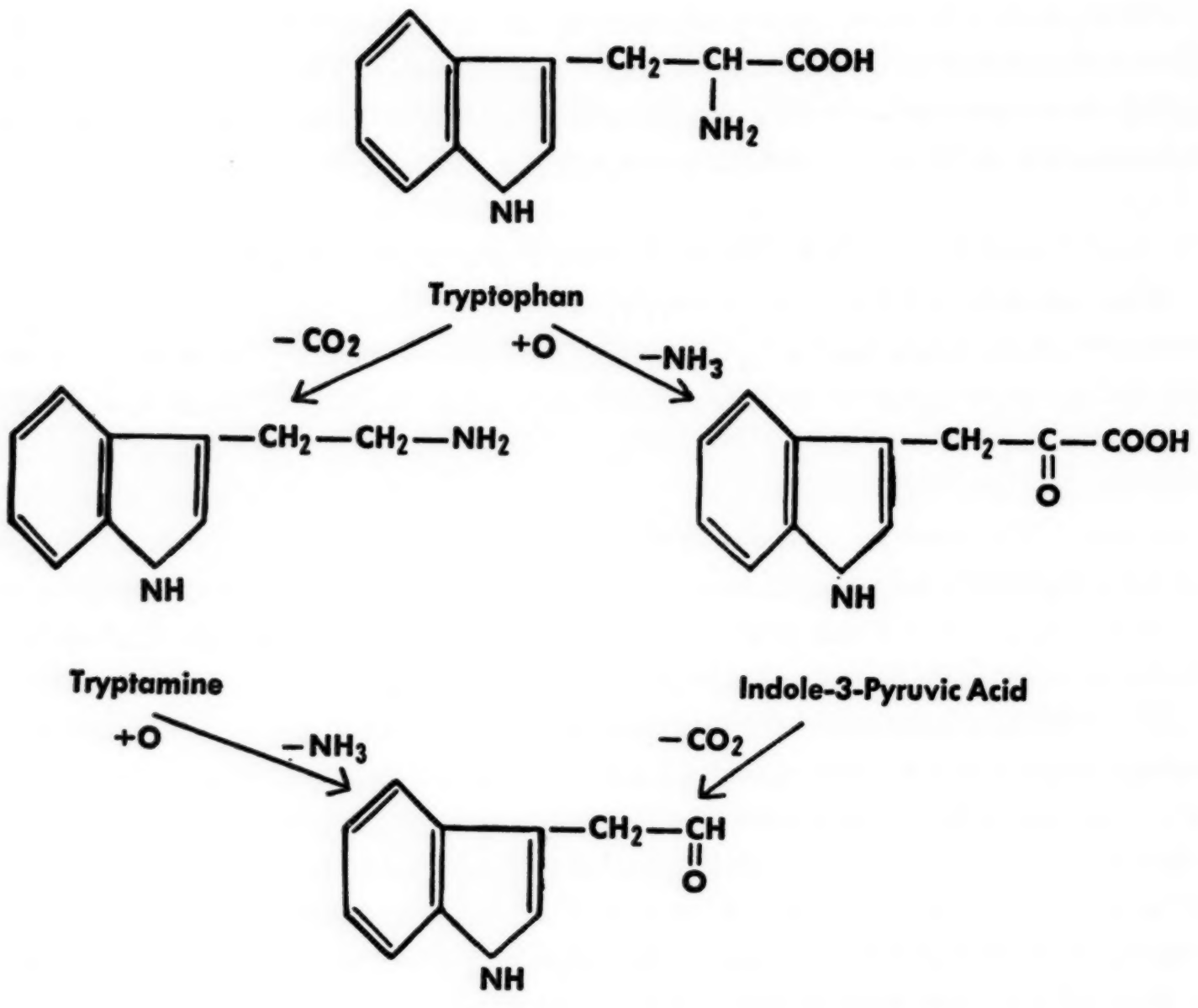
Skoog[64] has demonstrated that tryptophan, a common amino acid constituent in polypeptides, can act as a precursor for the synthesis of IAA. An enzyme system which catalyzes the production of IAA from tryptophan is known to occur in spinach leaves; possibly a similar conversion may occur in the human. Zinc deficiencies are linked with the conversion of tryptophan to IAA.[63, 82] Apparently zinc is necessary for the synthesis of tryptophan for unless this element is present in plant tissues the subsequent synthesis of IAA is suppressed.[82] For reaction sequence with postulated intermediates which has for many years been accepted as the chemical path leading from tryptophan to IAA[1, 24], see page 22.

This reaction sequence is based on a number of investigations with crude enzyme preparations derived primarily from plant sources. Evidence for some of the proposed intermediates is not overwhelming. Tryptamine, for example, which is postulated to arise from tryptophan after decarboxylation of the latter, has only been identified in two species of *Acacia*.[90] However, many enzyme preparations catalyze the conversion of tryptamine to IAA, though some do not.[92]

The occurrence of indole-3-pyruvic acid in plant tissues was pointed out earlier (see Table I), but the instability of the keto-acid has made it difficult to prove, beyond a doubt, its existence in the metabolic sequence. Gordon and Sanchez-Nieva[25] showed that crude enzyme preparations convert indole-3-pyruvic acid to IAA, while Kaper[33] found it an intermediate in the conversion of tryptophan to IAA by the bacteria, *Agrobacterium tumefaciens*. Under anaerobic conditions Kaper also found an accumulation of indole-3-lactic acid presumably formed from indole-3-pyruvic acid by reduction, catalyzed by a dehydrogenase.

Indole-3-acetaldehyde has been found in concentrations as high as 4 mg/kg in cabbage leaves.[39] The aldehyde can of course be converted readily to the acid.[40]

As far as the fate of phytohormones in human metabolism is concerned there is evidence that when IAA is fed to humans a conjugate is formed. The conjugate has been identified as indole-3-acetylglucosiduronic acid.[30] During studies on the biochemical lesion of Hartnup disease, Jepson *et al.*[30] at the Middlesex Medical



School in London fed normal subjects single doses of IAA and followed the subsequent changes in urinary excretion patterns. A 500 mg. oral dose of IAA was accounted for in the urine, over the subsequent 24 hour period; 200 mg. were present as glucuronide and the rest as free IAA. Many normal urines were found to contain traces of the glucuronide, which is rapidly converted to IAA and indole-3-acetamide under ammoniacal conditions. Urines from cases of Hartnup disease contain only moderate amounts of glucuronide. Jepson[30] reported that indole-3-acetylglucosiduronic acid will yield glucuronic acid and IAA by alkaline or enzymatic hydrolysis (utilizing B-glucuronidase). Although the metabolism of other indole hormones has yet to be studied in human subjects, it is of considerable interest that in the studies with IAA a conjugate was noted in the urine of patients fed the phytohormone. A similar situation has been reported[23] when IAA is "fed" to plant tissues; the conjugate formed is indole-3-acetylaspartic acid.

If similar conjugates are formed in the human when other of the indolic plant hormones are ingested in foods, it may well be that the process of conjugate-formation functions as a detoxification mechanism.

Although other indole-ring-containing compounds, such as serotonin, have assumed important physiological roles in the human, it is doubtful whether there is any clear-cut link between consumption of foods rich in indolic precursors and any subsequent increase in serotonin levels in the body. Nevertheless, as new knowledge of the naturally-occurring phytohormones accumulates, and more is learned of their role in human metabolism, future reviews on this subject may well find it necessary to discuss simultaneously the two topics.

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